

DEFECT IDENTIFICATION AND SIZING BY THE ULTRASONIC SATELLITE-PULSE TECHNIQUE

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ABSTRACT

Type and size are the most important defect characteristics that need to be determined for reliable prediction of the remaining service lifetime of a defective structure or part. The analytical and supporting experimental results presented in this paper concern a universal ultrasonic defect-identification-and-subsequent-sizing method. The conceived satellite-pulse technique (SPT) is based on the interpretation, in terms of defect types and dimensions, of the separation in time-of-arrival between the specularly-reflected pulse and its tip-diffracted or tangentially-scattered "satellite" contained in the composite defect signal. Several alternate calibration procedures were also developed, any one of which enables the ultrasonic examiner to make the time scale of the oscilloscope read directly in terms of equivalent crack depth or void diameter as appropriate.

Introduction

The current trend toward a defect-tolerant-design philosophy places increased importance on accurate ultrasonic defect-sizing techniques, because it requires the technique to estimate the size of a detected and identified defect with a specified probability and degree of confidence. The difficulties of present ultrasonic techniques in meeting the needs of fracture mechanics lifetime-prediction models can be attributed to several causes, all stemming principally from the poorly-established relationships between the peak amplitude of the reflected pulse and defect characteristics. A crack oriented perpendicular to the examination surface may produce a relatively weak reflected wave. A large compressive stress may close the crack and thereby diminish the reflected pulse amplitude. Other sizing difficulties are encountered when the defect is located in the "dead zone" of the ultrasonic probe.

The four materials evaluation tasks for the determination of structural integrity are listed in Table 1. The important ultrasonic issue that we are now faced with is what type and severity of defect are present. The next frontier for

Task	Objective
I. Defect Detection	"where?"
II. Defect Identification	"what type?" (void or crack like?)
III. Defect Characterization	"how big?" ("what size?") "what shape?" "what orientation?"
IV. Lifetime Prediction	"how severe is the problem?" "prognosis?"

Table 1. Materials evaluation tasks and their objectives.

ultrasonics is thus to provide quantitative information needed to distinguish between those small, nonpropagating, void-like defects that are "benign" with respect to failure and those significant, propagating, crack-like defects that are "malignant" or critical with respect to failure.

Ultrasonic Defect-Sizing Methods

Ultrasonic-signature-analysis methods currently available or under development for estimating the size of crack-like or void-like defects are listed in Table 2. It is convenient to group these techniques in three broad categories according to the kind of analysis performed on the received defect signal. Useful quantitative information about the characteristics of the defect with implications for structural performance and safety may be obtained by arrival-time analysis or frequency-content analysis of the defect signal distorted or otherwise modified in relation to a replica of the transmitted pulse. Analysis of the peak amplitude of the principal component of the composite defect signal is most useful for defect detection (Task I in Table 1).

Analysis	Technique
Peak AMPLITUDE	Artificial Defect Echo Comparison Backwall Echo Comparison Decibel Drop
FREQUENCY Content	Deconvolution Frequency Response
Arrival TIME	Impulse Response Delay Time Satellite Pulse (SPT)

Table 2. Ultrasonic defect-sizing methods.

Signal distortion may register in the time domain as "satellite-pulse" formation and in the frequency domain as amplitude modulation¹ (see Figure 3). Selection of a particular method of defect sizing and its accuracy are dependent on exploiting established relationships between defect type, shape, orientation, size, composition, tightness, and surface roughness and certain extractable ultrasonic signal parameters. The size of defects which are large compared to the wavelength of the employed ultrasound can be determined with adequate accuracy by conventional peak-amplitude-comparison techniques. However, small defects in areas of high mechanical or thermal stress may affect the service strength of the

structure or part sufficiently to warrant its rejection, and measurement of the peak amplitude of the principal component of the defect signal ("echo height") for sizing small defects is unreliable. Differences in the capabilities and limitations of the ultrasonic defect-sizing techniques listed in Table 2, with the exception of the last method, are reviewed elsewhere.² The ultrasonic satellite-pulse technique (SPT)* for defect indication and subsequent sizing is the subject of this paper.

Defect IDENTIFICATION by the Ultrasonic Satellite-Pulse Technique

The extension of delay-time analysis for sizing crack-like defects to identifying and sizing defects of all types has led us to the satellite-pulse technique. An infinite variety of shaped defects is possible; but it seems reasonable initially to consider only two types: planar, crack-like defects, and volumetric, void-like defects.** From these, most other defect shapes of interest could be constructed.

The physical principles and feasibility demonstration of the SPT for identifying void-like and crack-like defects are presented, respectively, in the following two sections.

Identification of Void-Like Defects

Whenever an ultrasonic wave reaches a distinct boundary, mode conversion, refraction, reflection, scattering, or diffraction occurs. The Rayleigh-type surface waves generated by an incident ultrasonic beam upon encountering a spherical or cylindrical void in a metal may be described in terms of the simple concepts of acoustic ray theory. Geometrical theories of scattering from relatively smooth, generally convex targets imbedded in homogeneous, isotropic, linear elastic media provide good results at relatively low frequencies.³⁻¹³ The models developed to describe the scattering of ultrasonic plane waves by volumetric defects do not account for materials attenuation effects which make the received specularly-reflected and tangentially-scattered pulse components of the defect signal inexact replicas of the transmitted pulse. Nor do these models predict the speed and attenuation of the signal components as they propagate along the various ray paths. An oversimplified model of scattering by a void in metal assumes that the speed of the "creeping wave" along the void's periphery is identical to that of the incident longitudinal bulk wave, c_p , rather than that of a Rayleigh surface wave.^{8,10-12} These authors derived a linear expression for the separation in time-of-arrival of the specularly-reflected and first pair of scattered pulses, Δ_0 , in terms of the void's diameter, d_0 , as shown below:

$$\Delta_0 = \frac{2.57d_0}{c_p} \quad (1)$$

*The SPT research and development program was sponsored by Southwest Research Institute. The concepts are covered in appropriate patent applications.

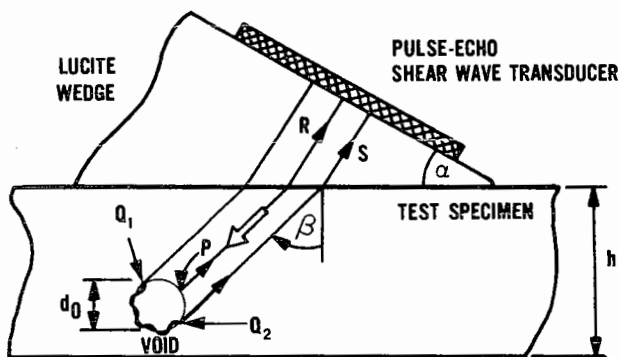
**Such broad defect classifications make a good deal of intuitive sense, and are supported by research findings.

Freedman^{4,5} assumed the backscattered signal for simple bodies of arbitrary convex shape to be composed of several discrete pulses, each identical to the transmitted pulse ("composite echo theory"). The first pulse is produced by the specular reflection of the incident wave at the point on the surface of the scattering defect nearest to the source of ultrasound. This follows from Fermat's principle of least action and geometrical acoustics considerations. Additional echoes are formed wherever there is a discontinuity in solid angle subtended at the pulse-echo probe by parts of the inclusion within range r or in its k th derivative with respect to range, $dK(r)/dr$. Separate scattered pulses are received only from certain discrete ranges of a volumetric defect. The magnitude of each scattered pulse is proportional to the magnitude of its generating discontinuity in the defect's shape function, $J(r)$, or its k th derivative, and it decreases with increasing frequency and defect diameter. Usually only the first one or two orders of derivative ($k = 0$ or 1) in which discontinuities occur need to be considered. The pulses are separated in time-of-arrival by the difference in times taken to travel to and return from the defect's "extremities" marked by the discontinuities in the k th derivative of its shape function. There are inherent difficulties in defining the discontinuities which contribute significantly to the composite echo structure of scatterers of arbitrary shape.

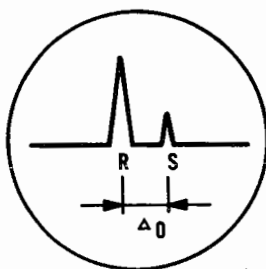
Rudgers⁷ developed a model for describing the scattering process by volumetric defects of simple shape based on the creeping-wave formalism. Rudgers' geometrical theory of scattering provides a simple explanation of the type-and-size-information-carrying pulse, S , in the ultrasonic signature of a hole drilled into the side of a test specimen (see Fig. 1). In the defect-characterization position, the incident ultrasonic beam is aimed at the center of the void of diameter d_0 so as to maximize the amplitude of the first pair of creeping waves which arrive at the pulse-echo shear wave transducer simultaneously after having traveled ("crept") once around the back surface of the void in opposite directions. For clarity, only the counterclockwise creeping wave is shown by the wiggly line from Q_1 to Q_2 in Fig. 1(a). When the ultrasound encounters the front surface of the void at point P , a specularly-reflected wave ("R-wave") is sent back to the transducer (front reflection). A pair of Rayleigh-type surface waves is also produced by the incident wave at points Q_1 and Q_2 . These Rayleigh waves circumvent the void a number of times until they disappear into the noise since their energy is continuously depleted by tangential radiation. Each time the counterclockwise creeping wave reaches point Q_2 , tangential reradiation, in the form of a tangentially-scattered wave ("S-wave") from the void during its circumvention, is launched at the desired detection angle to be received by the pulse-echo transducer (back scattering). The delay time between the R pulse and its first scattered satellite, Δ_0 , is a linear function of the void diameter, d_0 , as expressed by the relationship

$$\Delta_0 = \left(\frac{\pi}{2v} + \frac{1}{c} \right) d_0 \quad (2)$$

where c is the shear wave velocity and v is the Rayleigh wave velocity of the test specimen. This equation differs from Equation (1) in one respect:



- a. Splitting of the incident wave (hollow arrow) into a specularly-reflected component, R, and a circumferentially-scattered component, S, by a void of diameter, d_0 .



- b. Reflected and scattered pulses separated by delay time Δ_0 on the oscilloscope screen.

Fig. 1. The interaction of an ultrasonic shear wave with a void-like defect resulting in a reflected pulse and a lagging scattered satellite pulse.

the creeping wave travels along the defect's periphery with the Rayleigh velocity (rather than the bulk velocity).

The ratio of the Rayleigh and shear wave velocities, termed as the surface velocity ratio, m , is given by the Bergmann approximation,

$$m = \frac{v}{c} = \frac{0.87 + 1.12\sigma}{1 + \sigma}, \quad (3)$$

where σ is the Poisson ratio. In terms of the ratio of the longitudinal and shear wave velocities, termed as the bulk velocity ratio, n , Poisson's ratio is given by

$$\sigma = \frac{1 - 2n^2}{2 + 2n^2}. \quad (4)$$

For carbon steel 1020, Equation (2) becomes

$$c\Delta_0 = 2.71d_0. \quad (5)$$

The constant of this equation differs from that of Equation (1) (i.e., 2.57), and its validity was borne out by experimental results.

Void-like defects may, therefore, be distinguished from other reflector types (corners, notches, cracks, etc.) by their lagging satellite pulses.

Identification of Crack-Like Defects

For an axially-sited spherical cap target, Freedman's composite echo theory⁴ predicts two pulse components; the first is a reflected pulse that is the same as for a sphere, and the second pulse is formed by diffraction of the incident wave at the cap rim.⁴ The discontinuities in the first derivative of the spherical cap's shape function as a function of range, $J(r)$, are located at its nearest and farthest points relative to the source of ultrasound. Similarly, for an axially-sited right circular cone, there is a discontinuity in the second derivative of $J(r)$ at the cone apex or tip and another one in the first derivative of $J(r)$ at the cone base. At aspect angles other than axial or normal, there are three pulse components; one is associated with the apex and the other two originate from the nearest and farthest points on the base rim directly receiving ultrasonic energy. The sequence in which these tip- and edge-diffracted pulses arrive at the probe is a function of the aspect angle.

With the direction of the ultrasonic beam other than parallel to a disc's axis, an infinite number of discontinuities occur in the second derivative of $J(r)$ at the near and far ranges of the disc. Edge-diffracted pulses are thus expected to arise at these defect "limiting ranges." The diffracting "extremities" of the internal crack shown in Fig. 2 are at points Q_a and Q_b . A single

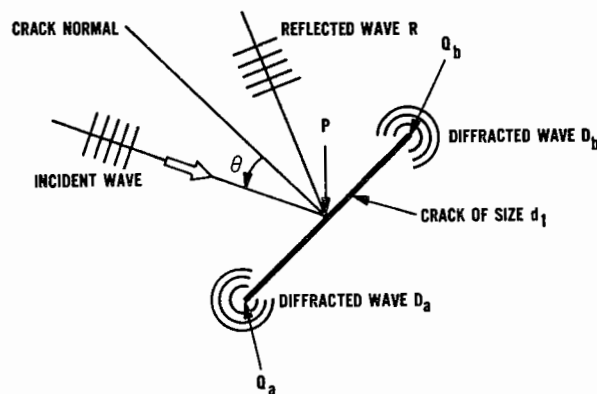


Fig. 2. The interaction of an ultrasonic shear wave with an internal crack resulting in a specularly-reflected wave and two tip-diffracted waves (adapted from Reference 15).

incident pulse splits into three parts; a specularly-reflected wave, R, which will not be received by the pulse-echo transducer, and two cylindrically-spreading, edge-diffracted waves, D_a and D_b . These waves are produced respectively at points P, Q_a and Q_b on the defect's surface. The separation in time-of-arrival of the edge-diffracted pulses is given by the delay time

$$\Delta_1 = \frac{2d_1}{c} \sin\theta, \quad (6)$$

where d_1 is the distance between the defect's extremities (i.e., crack depth) and θ is the angle the incident beam makes with the line perpendicular to the crack. The defect signal may be represented by the sum of two identical pulses:

$$s(t) = u(t + \Delta_1/2) + u(t - \Delta_1/2), \quad (7)$$

where $u(\cdot)$ denotes the form of the transmitted pulse. This composite waveform Fourier transforms into

$$|S(f)|^2 = |2\cos \pi\Delta_1 f|^2 |U(f)|^2. \quad (8)$$

The defect energy density spectrum is thus the same as that obtained for a specularly-reflected pulse, $|U(f)|^2$, modulated by the low-frequency cosine term involving the separation in time-of-arrival of the edge-diffracted pulses. The periodicity of the modulated spectrum is given by

$$p_1 = 1/\Delta_1. \quad (9)$$

Thus, defect size and orientation information in the time domain (i.e., Δ_1) carries over to the frequency domain (i.e., p_1) in a reciprocal manner. The feasibility of using waveform-distortion or spectrum-modulation information for estimating the size and orientation of crack-like defects is illustrated in Fig. 3. The ultrasonic responses of narrow slits of various depth ($d_1 = 100$ mils and 200 mils) and orientation ($\theta = 25^\circ$ and 32°) were determined to aid in the interpretation of the composite signal received from a turbine rotor fatigue crack. For purposes of comparison, the unmodulated reference spectra are also shown in envelope form in Fig. 3 along with the modulated signal spectra.

The temporal representations on the left side of Fig. 3 indicate two distinct echoes that originate from the secondary source points located at the bases and tips of the surface-breaking slits. The tip-diffracted pulses, D, arrive ahead of the larger base-reflected pulses, R. The spectral representations on the right side of Fig. 3 contain

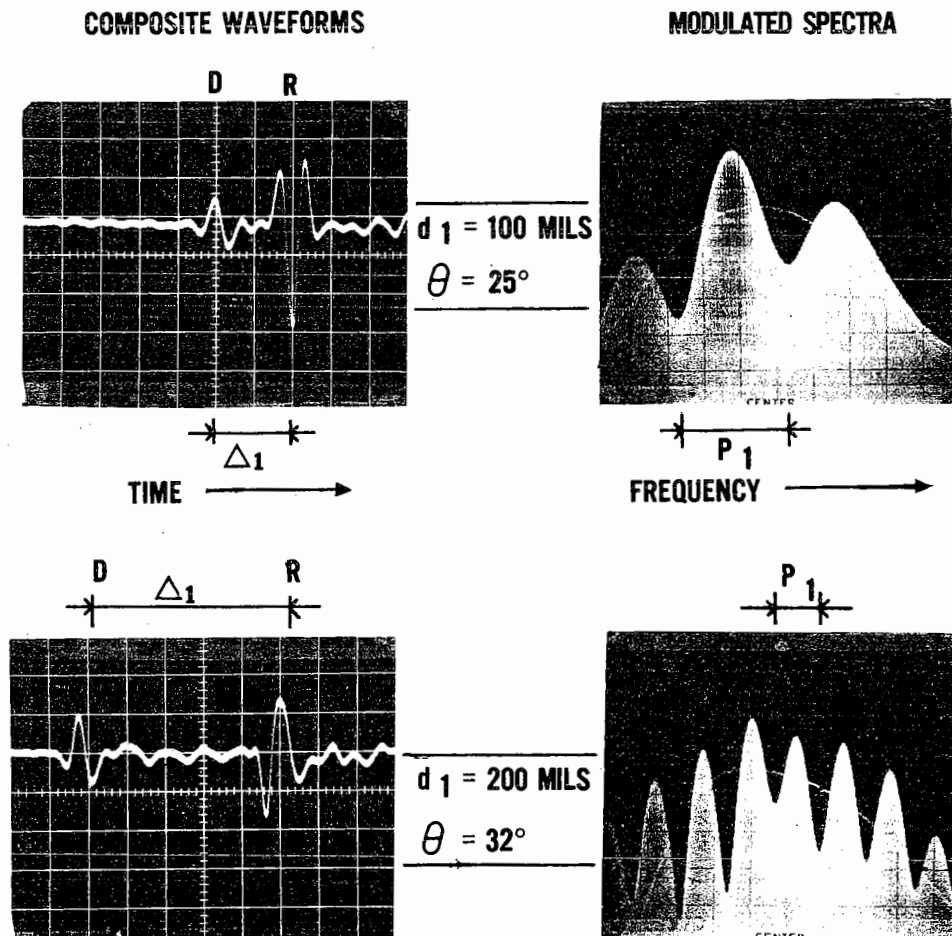


Fig. 3. Illustrating the inverse relationship between delay time, Δ_1 , and spectrum periodicity, p_1 , obtained for slits simulating surface-breaking fatigue cracks.

equivalent information.* Although the spectral approach has considerable potential for revealing details about important defect characteristics, the expertise and sophistication needed to acquire, process, and interpret the pertinent data limit its use to specialized applications. The field applications of frequency-content analysis for defect sizing thus have experimental difficulties. Arrival-time analysis yields advantages over spectral analysis not only in data acquisition but also in data processing and interpretation.

There are other mathematical models which have been developed to account for the ultrasonic diffraction process by planar defects. At high frequencies, Keller's geometrical theory of diffraction provides a simple explanation of the type-and-size-information-carrying extra pulse, D, in the ultrasonic signature of a surface-breaking crack^{17,18} [see Fig. 4(b)]. The geometrical theory of diffraction assumes that when the obliquely-incident ultrasonic beam encounters a surface-breaking crack such as that shown in Fig. 4(a), in addition

to the generally observed reflected wave, R, a diffracted wave, D, is produced when the beam encounters the tip of the crack at point Q. In the defect-characterization position, the incident ultrasonic beam is aimed at point Q so as to maximize the amplitude of the tip-diffracted wave. Upon the incident beam's encountering the base of the crack at point P, a corner-reflected wave is sent back to the transducer which arrives after the diffracted pulse [see Fig. 4(b)]. The delay time between the R-pulse and its diffracted satellite, Δ_1 , is a linear function of the crack depth, d_1 , as expressed by the relationship

$$\Delta_1 = \frac{2d_1}{c} \cos \beta, \quad (10)$$

where β is the angle the incident beam makes with the line perpendicular to the upper surface of the test specimen. For a refraction angle of 45 degrees, we obtain

$$c\Delta_1 = 1.41d_1. \quad (11)$$

Crack-like defects, may, therefore, be distinguished from other reflector types (corners, inclusions, voids, etc.) by their leading satellite pulses.

Defect SIZING by the Ultrasonic Satellite-Pulse Technique

The first two reflections from the test specimen's end, or from the end of a plain piece of similar material, may be used to eliminate the influence of the generally unknown shear wave velocity on the derived linear relationship between d_1 and Δ_1 in Equation (11) and on that between d_0 and Δ_0 in Equation (5). Figure 5 illustrates the simple calibration procedure that may be performed right on the specimen (i.e., without having notches and/or side-drilled holes available in a separate calibration block). The calibration delay time between the first two corner-reflected pulses from the end of a plate or pipe specimen of thickness h is given by

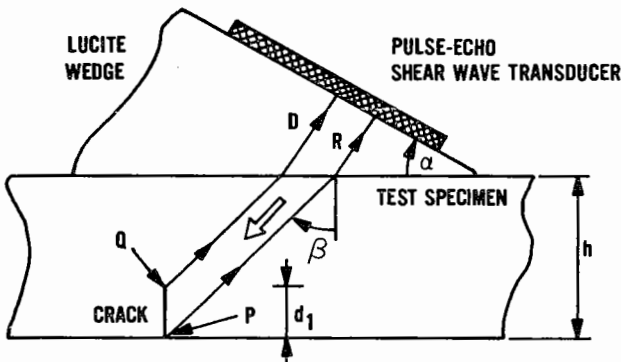
$$c\Delta_h = 1.41h. \quad (12)$$

Sizing of Crack-Like Defects

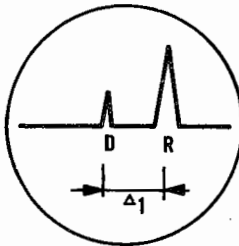
Division of Equation (12) by Equation (11) for $\Delta_1 = d_1$ yields the calibration equation for sizing crack-like defects:

$$\Delta_h = h \quad \text{for } \beta = 45^\circ. \quad (13)$$

This means that if we adjust the time scale of the oscilloscope to read h units between the first two reflections obtained with a 45-degree beam from the test specimen's end, or from the end of a plain piece of similar material, the depth of the crack-like defect can be read directly in mils or millimeters on the oscilloscope screen, provided that the examination is carried out with a 45-degree shear wave.



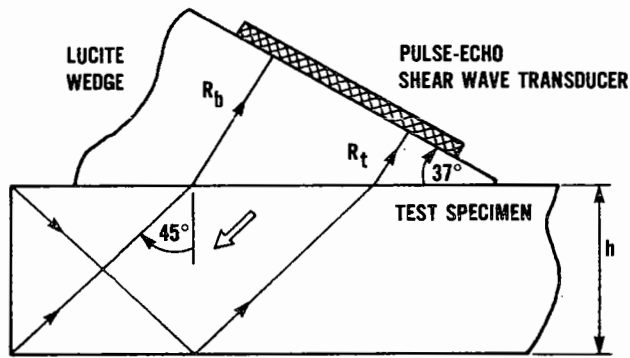
- a. Splitting of the incident wave (hollow arrow) into a corner-reflected component, R, and a tip-diffracted component, D, by a crack of depth d_1 .



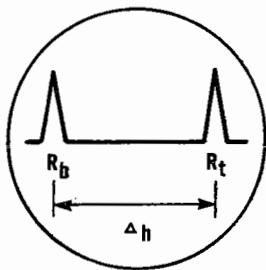
- b. Reflected and diffracted pulses separated by delay time Δ_1 on the oscilloscope screen.

Fig. 4. The interaction of an ultrasonic shear wave with a crack-like defect resulting in a reflected pulse and a leading diffracted satellite pulse.

*The spectral representations of the defect's response actually provide less information since no phase information is present at the output of the spectrum analyzer.¹⁶



- a. Splitting of a 45-degree incident wave (hollow arrow) into a bottom-reflected wave, R_b , and a top-reflected wave, R_t , by the end of a steel specimen.



- b. Bottom and top-reflected pulses separated by the calibration delay time, Δh , on the oscilloscope screen.

Fig. 5. The interaction of a 45-degree ultrasonic shear wave with the test specimen's end resulting in two reflected waves.

For a refraction angle of 60 degrees, the calibration equation becomes:

$$\Delta h = 1.41h \quad \text{for } \beta = 60^\circ. \quad (14)$$

This means that if we adjust the time scale of the oscilloscope to read 1.41h units between the first two reflections obtained with a 45-degree beam from the test specimen's end, or from the end of a plain piece of similar material, the depth of the crack-like defect can be read directly in mils or millimeters on the oscilloscope screen, provided that the examination is carried out with a 60-degree shear wave.

Notches and steps were used in proof-of-principle measurements since their depth could be determined visually without breaking open the test specimens. The results shown in Fig. 6 are of particular interest since they provided an early confirmation of the potential of the direct-sizing SPT. The experiments were carried out using 45- and 60-degree shear-wave probes and a range of frequencies (2 to 4 MHz) and defect locations (0.05 to 2 inches) in six different steel specimens with otherwise unspecified properties. The ultrasonic estimates of slit depth compare very favorably with the visual measurements of slit depth.

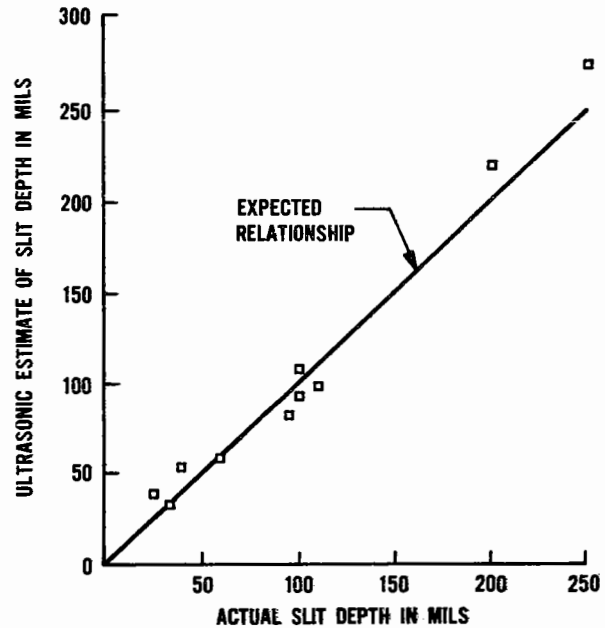


Fig. 6. Illustrating the one-to-one correspondence between the ultrasonically estimated and visually determined slit depths.

The SPT has now been used to size a number of laboratory and inservice-produced fatigue and intergranular stress corrosion cracks in steel specimens. The results of SPT measurements for a fatigue crack in a turbine rotor specimen are shown in Figs. 7 and 8. Both methods of "attack" and operating frequencies yielded depth estimates for the fatigue crack at its deepest mid-length point of 115 mils.

Sizing of Void-Like Defects

Division of Equation (12) by Equation (5) for $\Delta_0 = d_0$ yields the calibration equation for sizing void-like defects:

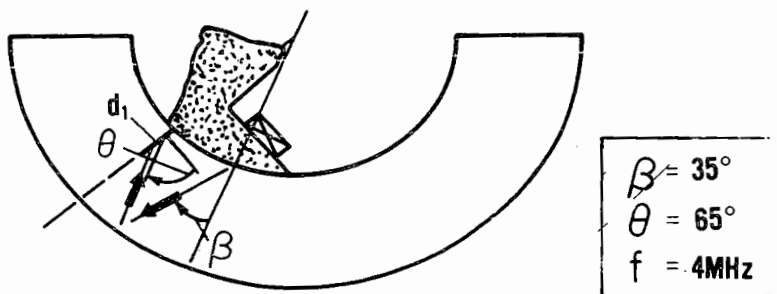
$$\Delta h = 0.52h \quad \text{for any } \beta. \quad (15)$$

This means that if we adjust the time scale of the oscilloscope to read 0.52h units between the first two reflections obtained with a 45-degree beam from the test specimen's end, or from the end of a plain piece of similar material, the diameter of the void-like defect can be read directly in mils or millimeters on the oscilloscope screen, regardless of the refraction angle of the ultrasonic beam.

Figure 9 reveals that the experimental results are in keeping with the main predictions of the satellite-pulse model derived for void-like defects in metals. The data were obtained over a range of frequencies (2 to 4 MHz) and defect locations (0.05 to 1.3 inches) in four different steel plates with otherwise unspecified properties. The time scale of the oscilloscope was recalibrated each time the hole was in a different plate. The agreement between the ultrasonically and visually determined hole diameters is seen to be excellent.

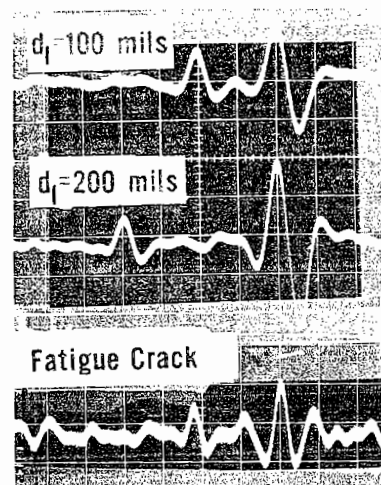
Conclusions

The results obtained so far are very encouraging. In view of the improved defect discrimina-



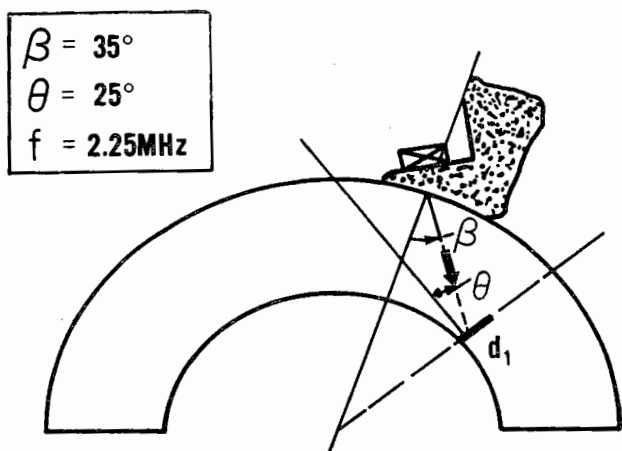
a. Probe position for sizing crack-like defects breaking the accessible surface.

Fig. 7. SPT-sizing of a laboratory-produced fatigue crack in a turbine rotor specimen breaking the accessible surface.



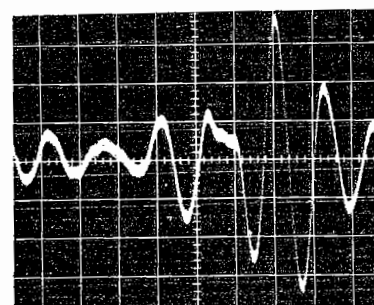
b. Tip-diffracted pulses preceding corner-reflected pulses in the composite ultrasonic signature of narrow slits (upper and middle traces) and the fatigue crack (lower trace).

Scale: $\text{---} 50 \text{ mils}$



a. Probe position for sizing a fatigue crack breaking the inaccessible surface.

Fig. 8. SPT-sizing of a laboratory-produced fatigue crack in a turbine rotor specimen breaking the inaccessible surface.



b. Ultrasonic signature of a fatigue crack of unknown depth.

Scale: $\text{---} 50 \text{ mils}$

tion and sizing capability offered by the SPT, it would be preferable to replace the sole use of the peak amplitude of the reflected pulse component in the characterization of an already detected defect by less ambiguous signal parameters. The most suitable signal parameter for this purpose appears to be the separation in times-of-arrival between the resolved pulse components of the defect signal (i.e., Δ). The usually smaller extra pulses (i.e., the satellites) have been shown to originate from the sharp diffracting edge boundaries of a crack-like defect and from the smooth scattering shadow boundaries of a void-like defect.

The ultrasonic SPT for defect identification and sizing is especially attractive in terms of reliability and simplicity of operation. Unique

features and other advantages of the developed technique include:

- its general applicability;
- independence of signal parameter (i.e., Δ) from the peak amplitudes of the associated echoes;
- independence of signal parameter from defect location;
- independence of signal parameter from operating frequency;
- linear relationship of signal parameter to defect size;

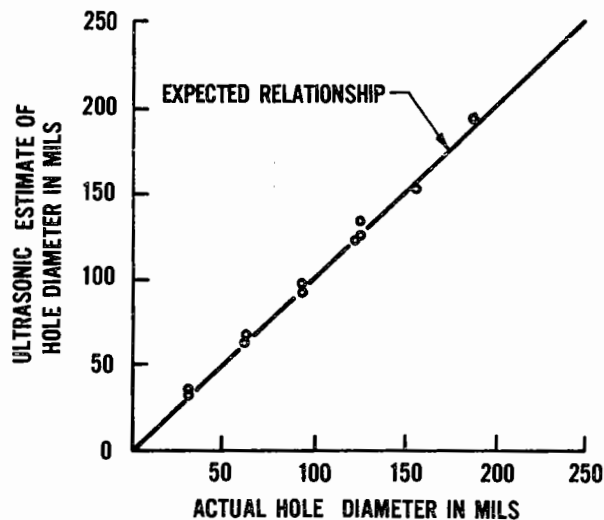


Fig. 9. Illustrating the one-to-one correspondence between the ultrasonically estimated and visually determined side-drilled-hole diameters.

- ease of calibratability of ultrasonic apparatus;
- direct readability of defect size on the oscilloscope screen;
- use of single probe; and
- use of standard equipment and probes.

The SPT is immune to variations in reflected, diffracted, and scattered pulse amplitudes which occur with variations in material properties, defect location, ultrasonic coupling efficiency, operating frequency, etc. The ultrasonic data required for defect identification and sizing may be acquired by a single pulse-echo shear wave transducer with equipment currently used in ultrasonic testing and evaluation of materials. The ultrasonically determined defect sizes were within 10 percent of the actual values over a 2-inch defect location range. A simple calibration procedure for making the time scale of the oscilloscope of the ultrasonic apparatus read directly in terms of equivalent crack depth or void diameter, as appropriate, was also developed which bypasses the need for notches and side-drilled holes in separate calibration blocks.

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SUMMARY DISCUSSION
(G. J. Gruber)

J. K. White (Westinghouse Research): It seems to me there is an effect, a modulation effect, both of depth and of angle and of flaw size. Presumably you separate out the depth effect by gating only a certain portion of the signal. How do you separate out the angle? By making sure you're perpendicular to the reflection?

George Gruber: I have to make more measurements. We never did get to the crack sizing situation. The relationship between delay time, Δt , D-1, which is the depth and sound speed, and it's also the orientation angle that's involved. So, what I have is three unknowns, four unknowns. Δt I can measure okay; C I eliminated by the calibration technique. Same sort of things that went for the pulse. I have to make two measurements, at least, because I got two unknowns, the size and the orientation. What I'll do is know my θ that I'm sending in, make two measurements, and I have eliminated two unknowns. So I can make one more measurement. If I don't know the orientation, if it's cracked, if it's a hole like, if it's axially symmetric, then I just make one measurement. Then I can only expect to get from the tip. But if it's curving on me, it's not perfectly in a plane, then of course I can only give you equivalent depths, which sometimes is important.

N. K. Batra (Systems Research Lab): In addition to the size, your beam must cover both the tips; is that right?

George Gruber: Yes. A round focus transducer. And it looks relatively big compared to the thicknesses of the place that I'm looking for. Actually, it works down to one tenth of an inch below the surface. It picks up and gives you the same information, independent frequency, the location, a lot of niceties that this has. I must admit one of the disadvantages--and it ties in nicely with the previous speaker's topic--is to lift it out from the microstructure nodes, that could be the problem. As you will see, those signals from the crack tip are not big.

N. K. Batra: I have a question then. If the crack is very large, say larger than your beam spread, then what do you do? You can't scan because you want to see both --

George Gruber: You use a transducer this big (indicating). I would think there are other methods of doing it better ways. This is aimed at sizing very small defects, and I'm going down and down right now, and the resolution is about half a milliliter in about 20 mills, and I'm going up in frequency trying to eliminate the noise. All kinds of improvements are needed here, but this is right now in a very unoptimized state, but still now I have it down to a half a millimeter.

Paul Holler (Inst. fur Zerst. Pruf.): That's better than your other method.

George Gruber: The amplitude method works good, but the oscillation disappears.

Paul Holler: I would like to commend that the goal of this paper is to classify whether it is a crack or not. In the philosophy or strategy in our country, it is very important because we have--also in this country--the experience that only a few percent of the indications we have are worthwhile to be handled later. So, I just want to give this headline -- or this remark because in the explanation of strategies, also in your paper, I was missing this point. In our country it's one of the very basic things, to find out whether a defect makes a stress concentration or not. And this is one of the goals -- one of the ways to solve it. But there are several others, and one not mentioned work is published on this using the derivative, but I do not want to start a new discussion.

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